Endophytes Isolated from Dayak Onion Flower Enhance Shallot Growth and Suppress Fusarium Wilt Disease

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ABSTRACT

Fusarium wilt, caused by *Fusarium oxysporum*, is a major constraint to shallot production and is commonly managed using synthetic fungicides that may generate ecological risks and chemical residues. Endophytic fungi from medicinal plants offer a promising biological-control alternative because they can suppress pathogens while supporting plant growth. This study evaluated extracts of two endophytic fungi isolated from Dayak onion (*Eleutherine palmifolia* (L.) Merr.) flowers, EnI (*Fusarium solani*) and EnK (*Neoscytalidium* sp.), for their ability to reduce Fusarium wilt and improve shallot growth under in vivo conditions. Shallot plants were treated with endophytic fungal extracts, challenged with *F. oxysporum*, and assessed for disease incidence, disease severity, plant height, number of leaves, and fresh weight. The application of Dayak onion flower endophytic fungal extracts reduced Fusarium wilt incidence and severity by up to 50% compared with pathogen-infected plants without endophytic treatment. Treated plants also showed improved vegetative growth and fresh weight, with higher plant height, leaf number, and biomass than untreated or pathogen-only plants. These findings indicate that Dayak onion flower endophytic fungal extracts have potential as environmentally friendly biocontrol agents for managing Fusarium wilt while enhancing shallot growth.

Keywords: Biological control; Dayak onion; endophytic fungi; *Fusarium oxysporum*; shallot

INTRODUCTION

Shallot (*Allium ascalonicum* L.) is an economically important crop in Indonesia, with demand increasing each year (Wibowo & Surbakti, 2023). However, productivity remains constrained by cultivation practices, poor soil fertility, limited water availability, climate change, pest attacks, and Fusarium wilt. Indonesian shallot production declined from two million tons in 2021 to 1.97 million tons in 2022 (BPS, 2022), indicating that production growth has not kept pace with demand. Fusarium wilt is particularly important because it reduces tuber production in both nursery and field conditions (Herlina et al., 2020) and can cause yield losses of up to 50% (Trizelia et al., 2023).

Long-term control of Fusarium wilt requires approaches that suppress the pathogen without damaging the environment or leaving harmful residues. Biological control using endophytes and other beneficial organisms is, therefore, a promising alternative to synthetic pesticides. Endophytic fungi are beneficial fungi that live within healthy plant tissues (Aziza et al., 2022). The relationship between endophytes and their host plants is often mutualistic because they can produce mycotoxins

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and other secondary metabolites that alter host physiology and biochemistry, thereby inhibiting the development of plant pathogens (Sari, 2020).

Dayak onion is a promising local biological resource for shallot disease management because its flower contains high bioactive compounds, including flavonoids and phenols, that are associated with antifungal activity (Shi et al., 2019). These bioactive properties provide a rationale for isolating endophyte fungi from Dayak onion flowers. Endophytes may produce metabolites similar to those of their host plants, helping endophytic fungi to establish symbiosis, evade plant immune responses, and contribute to the host's adaptive fitness (Vanmathi et al., 2026). Plant-colonizing fungi are increasingly studied because they can inhibit pathogens and promote plant development, making fungal endophytes and their metabolites a sustainable approach for reducing the long-term reliance on pesticides in agricultural systems (Dutta & Banerjee, 2024). When compared to the unprimed control, endophytic-primed plants had increased shoot and root length (Chaudhary et al., 2023). Fungal endophytes have advanced as probable biological agents to improve plant yield (Díaz-González et al., 2020).

Crude extracts of fungal endophytes have been reported to suppress pathogen mycelial growth (Segaran & Sathiavelu, 2023). A previous study also showed that the endophytic fungal extracts from the Dayak onion flower inhibited *Fusarium oxysporum* mycelial on PDA, with *Fusarium solani* EnI producing 71.09% and *Neoscytalidium* sp. EnK producing 38.54% inhibition (Rizali et al., 2021). These findings suggest that endophytes from Dayak onion flowers may have antifungal potential, but their effectiveness against Fusarium wilt in living shallot plants still requires in vivo evaluation. In addition, endophytic fungi may support plant growth, which could strengthen plant defenses against pathogen attack.

Based on this background, endophytic fungal extracts from Dayak onion flowers, particularly *F. solani* EnI and *Neoscytalidium* sp. EnK needs to be evaluated under in vivo conditions to determine whether their previously reported in vitro antagonistic activity can protect shallot plants from Fusarium wilt. This study aims to determine the effect of endophyte fungal extracts on fusarium wilt incidence and severity, as well as on shallot growth and yield parameters. By evaluating disease suppression and plant performance together, this study supports the development of safer and more environmentally friendly disease control strategies while optimizing the potential of Kalimantan native plants as sources of endophytic fungi for shallot production.

MATERIALS AND METHODS

Endophytic fungi isolation and purification

Dayak onion flowers were washed under running water to remove soil, dust, and surface debris. The plant segments were then surface sterilized by immersion in 70% alcohol for 30 s and soaked in 1% NaOCl for 2 min, rinsed 3 times with sterile distilled water, and dried on sterile tissue. The sterilized segments were placed on PDA medium, incubated, and purified to obtain endophytic fungal isolates. Two isolates were identified as *Fusarium solani* EnI and *Neoscytalidium* sp. EnK using PCR amplification of the fungal ITS region with ITS1 and ITS4 primers (Rizali et al., 2021).

Extraction of Endophytic Fungi Isolates EnI (*Fusarium solani*) and EnK. (*Neoscytalidium* sp.) and the pathogen *Fusarium oxysporum*.

Mycelia from endophytic fungal isolates EnI and EnK and the pathogen *Fusarium oxysporum* were transferred aseptically to PDA medium using an inoculating needle and incubated for 7 days. The endophytic fungi were then cultured in potato dextrose broth on a rotary shaker at 120 rpm for 21 days at 25°C (Farouk et al., 2023). The mycelia and culture filtrates were separated using Whatman No. 42 filter paper with a pore size of 2.5 µm. The culture filtrate was macerated with ethyl acetate at a 1:1 ratio and n-hexane at a 10:1 ratio (Segaran & Sathiavelu, 2023), whereas the mycelia were macerated separately with ethyl acetate and n-hexane at a 1:5 ratio. The maceration and extraction processes were repeated three times (Rizali et al., 2021). The solvent was evaporated using a rotary evaporator, and resulting extracts were stored at 14°C.

Seed Treatment

Shallot bulbs were surface-sterilized with 1% NaOCl for 3 minutes and rinsed three times with sterile distilled water. The bulbs were then soaked for 30 minutes in an endophytic fungal suspension prepared by 30 ml of spore suspension at 6 x 10^6 spores/ml with 100 ml of sterile aquades. After soaking, the treated bulbs were dried in an oven at 37°C for 12 hours (Novitasari & Munif, 2023).

Application of Endophytic Fungi Extract of Dayak Onion Flower EnI and EnK in Medium of Plant

Three kilograms of planting medium consisting of soil and compost at a 1:1 ratio were placed in each polybag. The upper one-third of each treated shallot bulb (from seed treatment) was cut, and the bulbs were planted approximately 2 cm deep in the planting medium. After two weeks, the seedlings were transplanted into polybags. The treatment combinations were as follows: FsMEnI (seed treatment) EnI + EnI extract + *F. oxysporum*); FsMEnK (seed treatment EnI + EnK extract + *F. oxysporum*); FsMEnI + FsMEnK (seed treatment EnI + extract (EnI+EnK) + *F.oxysporum*); MEnI + MEnK (seed treatment EnI + extract (EnI+EnK)); Fs (*F.oxysporum*); and control (no treatment).

For each treatment containing endophytic extract, 100 ml of solution was prepared by mixing 10 ml of endophytic fungal extract with 90 ml of distilled water. The solution was applied to each polybag at 2, 3, and 4 weeks after planting by making a hole around the shallot roots, pouring the extract solution into planting medium, and covering the hole again (Saputra, 2020).

Application of the suspension of the pathogen *Fusarium oxysporum* in planta

The *Fusarium oxysporum* suspension was prepared by adding 10 ml of sterile distilled water to a pure fungal culture and gently scraping the colony surface to release spores. The suspension was transferred to a test tube, vortexed to separate spores from mycelia, and diluted from 10^2 to 10^6. At 3 weeks after planting, 10 ml of *F.oxysporum* suspension at 6 x 10^6 microconidia/ml was applied to each polybag by making a hole around the shallot roots, pouring the suspension into the planting medium, and covering the hole again (Rahmiyati et al., 2021; Saputra, 2020).

Measurement of the Growth and Yield of Shallot

Plant height was measured weekly 2 to 8 weeks after planting using a ruler and expressed in centimeter. Height was measured from the plant base to the tip of the tallest leaf. The number of leaves was recorded weekly from 2 to 8 weeks after planting by counting all the leaves on each plant. Shallots were harvested 11 weeks after planting by removing the whole plant from the medium and cleaning off the remaining soil. Plant fresh weight was measured using a digital scale and expressed in grams (g).

Incidence and Disease Severity of Fusarium Wilt of Shallot

Disease incidence was observed from 5 to 8 weeks after planting. Disease incidence was calculated as the percentage of plants showing Fusarium wilt symptoms relative to the total number of plants observed, using the following formula:

$$KP\ (\%) = \frac{\mathrm{n}}{\mathrm{N}} \times 100\% \qquad (1)$$

Note:
KP: disease incidence
n: Number of plants showing the fusarium wilt symptoms
N: Total plants observed

Disease severity was determined as the percentage of plant tissue showing Fusarium wilt symptoms. Symptoms were scored using a 0–4 scale: 0 = no symptoms, 1 = 1–10% twisted leaves, 2 = 11–30% twisted leaves, 3 = 31–75% twisted leaves, and 4 = ≥76% twisted leaves. Observations were conducted from 5 to 8 weeks after planting, and disease severity was calculated using the following formula:

$$KeP/IP = \frac{\Sigma \mathrm{ni} \times \mathrm{vi}}{\mathrm{z} \times \mathrm{N}} \times 100\% \qquad (2)$$

Note:
KeP/IP: disease intensity
ni: number of affected plants in each category
vi: category (score) of attack, with categories (0 = No symptoms, 1 = 1-10% of the leaves are twisting, 2 = 11-30% of the leaves are twisting, 3 = 31-75% of the leaves are twisting, 4 = ≥76% of the leaves are twisting) (Hadiwiyono et al., 2020)
Z: highest attack category
N: total of the number of tissues observed

RESULTS AND DISCUSSION

Endophytic fungal extracts from dayak onion flowers EnI and EnK showed different responses to shallot growth under Fusarium wilt pressure, as shown by changes in plant height (Figure 1).

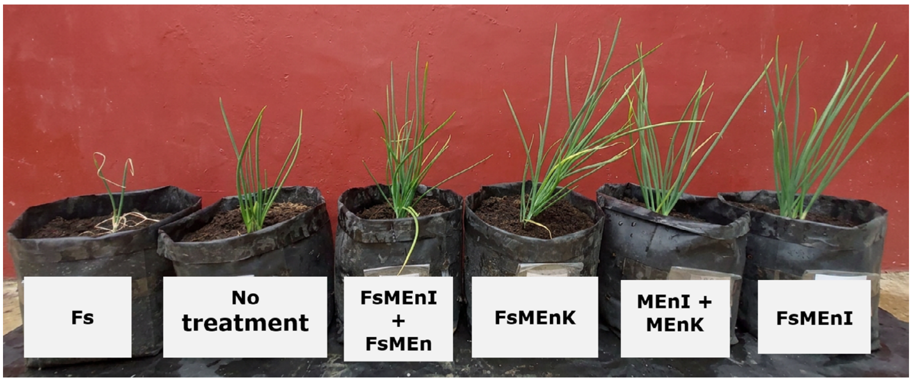

Figure 1. Comparison of the height plant that applied with extracts of endophytic fungi *(F. solani* EnI), EnK (*Neoscytalidium* sp.) and pathogen *F. oxysporum*. The treatments were **(Fs)** pathogen *F.oxysporum*; **no treatment**; **FsMEnI+FsMEnK**: endophytic fungi extract *Fusarium solani* (EnI) and *Neoscytalidium* sp. (EnK)+pathogen *F. oxysporum*; **FsMEnK**: endophytic fungi extract *Neoscytalidium* sp. (EnK)+ pathogen *F. oxysporum*; **MEnI+MEnK**: endophytic fungi extract *F. solani* (EnI) and *Neoscytalidium* sp. (EnK); **FsMEnI**: endophytic fungi extract *F.solani* (EnI)+ pathogen *F. oxysporum*

Plant height increased following the application of endophytic fungus extracts of dayak onion flowers. The plant height for the MEnI + MEnK treatment was 6.5 cm higher than the control at 8 weeks (Figure 2). This indicates that using extracts from the endophytic fungi EnI and EnK can enhance the height of shallot plants. The sample treated with endophytes, which are FsMEnI, FsMEnK, and FsMEnI + FsMEnK, had higher values of 5.75 cm, 8.25 cm, and 11.5 cm, respectively, compared to plants that were just infected by Fs, which do not have protection from fungi endophytes. Inducing plant resistance from the disease can be done indirectly by promoting the growth of the plant. This system, called multitrophic interaction between beneficial microbes in the belowground, can induce resistance by growth promotion on the plant (Sari, 2020). The plant infected only with the pathogen showed the lowest height; this is due to the infection of *F. oxysporum,* which causes disruption of the photosynthesis process to ultimately inhibit plant height growth.

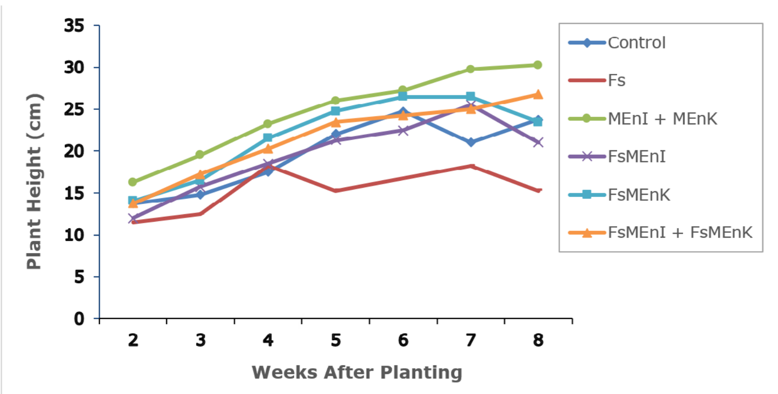

Figure 2. The average plant height of Dayak onion applied with endophytic dayak onion flower fungus extracts EnI and EnK and pathogen *F.oxysporum* week 2 to 8 after planting. (n=4). **Control**=no treatment**; Fs**: pathogen *F.oxysporum*; **MEnI+MEnK**: endophytic fungi F. *solani* (EnI) and *Neoscytalidium sp.* (EnK); **FsMEnI**: endophytic fungi extract F.solani (EnI) + pathogen *F. oxysporum*; **FsMEnK**: endophytic fungi *Neoscytalidium* sp. (EnK)+ pathogen *F. oxysporum* ; **FsMEnI+FsMEnK**: endophytic fungi *Fusarium solani* (EnI) and *Neoscytalidium* sp. (EnK)+pathogen *F. oxysporum*

The use of endophytic fungus extracts has a role in increasing plant height growth (Figure 2), despite the presence of the pathogen *Fusarium oxysporum* in the planting medium. Host plants and endophytic fungi have a mutually beneficial relationship where endophytic fungi get a place to develop, and host plants have benefits for protection from pests and diseases and increased plant growth (Gustianingtyas et al., 2021).

Shallots that were applied with endophytic fungal extracts of dayak onion flower EnI and EnK had more leaves compared to the plants that were not applied with endophytic fungi. As we can see, the average number of leaves at 8 weeks after planting in the MEnI + MEnK treatment was 4 leaves higher than the control (Figure 3). Thus, treatments FsMEnI, FsMEnK, and FsMEnI + FsMEnK had a higher number of leaves than the Fs treatment. Endophytic fungi can be a biocontrol agent to reduce damage to plants and increase host plant growth, such as increasing the number of leaves on the host plant. Endophytic fungi, both extracts and biological agents, can help the absorption of nitrogen nutrients that play a role in the growth and development of the number of leaves so as to produce many and fresh leaves (Al Falaq, 2020). Fungi endophytes have demonstrated a strong ability to promote plant development in various tests, including those that measure cellulose degradation, amylase production, phosphate solubilization, IAA generation, and ammonia production (Patyal et al., 2023).

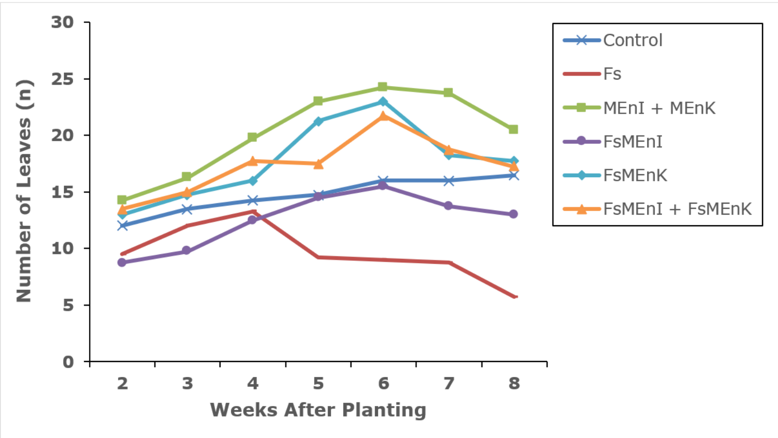

Figure 3. The average number of shallot leaves applied with extracts of endophytic fungi EnI and EnK and pathogen *F. oxysporum* week 2 to 8 after planting (n=4). **Control**=no treatment**; Fs**: pathogen *F.oxysporum*; **MEnI+MEnK**: endophytic fungi F. *solani* (EnI) and *Neoscytalidium sp.* (EnK); **FsMEnI**: endophytic fungi extract F.solani (EnI) + pathogen *F. oxysporum*; **FsMEnK**: endophytic fungi *Neoscytalidium* sp. (EnK)+ pathogen *F. oxysporum* ; **FsMEnI+FsMEnK**: endophytic fungi *Fusarium solani* (EnI) and *Neoscytalidium* sp. (EnK)+pathogen *F. oxysporum*

The application of endophytic fungus extracts of dayak onion flowers EnI and EnK have significantly increased fresh weight compared with the no-treatment plant (Figure 4). Infection by F. oxysporum damages plant photosynthesis, preventing proper growth and resulting in small bulbs. Shallots infected by Fusarium wilt do not decay and remain alive, but plants cannot grow optimally, and the bulbs formed are very small due to inhibition of photosynthesis, respiration, and nutrient translocation, especially in the formation of bulbs so as to reduce the weight of shallot plants (Hotim et al., 2020).

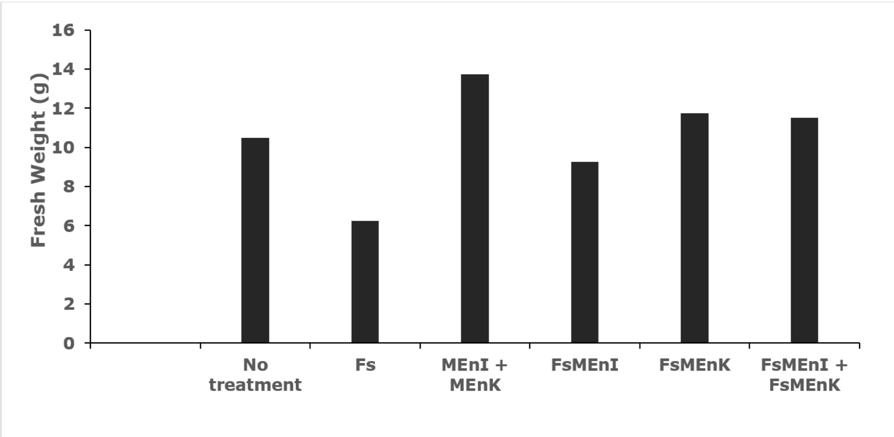

Figure 4. The average fresh weight of Dayak onion plants applied with extracts of endophytic fungi EnI and EnK and pathogen *F. oxysporum* at 11 weeks after planting (n=4, Duncan=Sig 0.05). **Control**=no treatment**; Fs**: pathogen *F.oxysporum*; **MEnI+MEnK**: endophytic fungi F*. solani* (EnI) and *Neoscytalidium sp.* (EnK); **FsMEnI**: endophytic fungi extract F.solani (EnI) + pathogen *F. oxysporum*; **FsMEnK**: endophytic fungi *Neoscytalidium* sp. (EnK)+ pathogen *F. oxysporum* ; **FsMEnI+FsMEnK**: endophytic fungi *Fusarium solani* (EnI) and *Neoscytalidium* sp. (EnK)+pathogen *F. oxysporum*

The fresh weight of shallots applied with Dayak fungal endophyte extracts EnI and EnK together with the pathogen has shown better results than the plant with the pathogen alone. In Figure 4, the plants that the pathogen *F. oxysporum* had been inoculated with have the lowest fresh weight, 6.25 g, compared to plants that had previously been treated with the fungal endophytes of dayak onion flowers, EnI and EnK, which each had a higher value significantly: FsMEnI 9.25 g, FsMEnK 11.75 g, and FsMEnI + FsMEnK 11.5 g. The plant that applied with endophytic fungal extracts has a role to activate the plant defenses; it is called induced systemic resistance. Induced systemic resistance has two ways to protect the host plant: it promotes its growth and produces the mycotoxin or antibiotics that inhibit pathogen growth in the rhizosphere. As reported by Fontana et al. (2021), endophytic fungi have beneficial properties for their hosts, which can improve plant health and yield while maintaining the quality and resistance of plants from pathogens and abiotic stresses.

Plants with endophytic extract treatments show better results, as reported by Dutta & Banerjee (2024). When compared to the untreated ones, a fungal extract treatment significantly improves the experimental plant's (tomato seedlings') growth in terms of relative water contents, dry weight, nodal length, and pigment profiles. Moreover, this result was also found by Pablo & Pablo (2020) that aseptically grown rice seeds and seedlings treated with endophytes showed markedly increased germination, seedling vigor, shoot, root, and overall plant growth-promoting levels. It has been shown that endophyte-colonized plants greatly benefit from these symbiotic relationships and that endophytic species can affect a variety of activities of their related host plants (Bamisile et al., 2021).

Table 1 showed that the fusarium wilt attack started at 5 weeks after planting. The percentage of disease incidence at 5 weeks of planting was 50% Fs treatment and 25% FsEnI, while FsMEnK and FsMEnI + FsMEnK did not experience a fusarium wilt attack, so it is known that the endophytic fungus extract of the Dayak onion flower EnK and the combination of endophytic fungus extract EnI + EnK are able to protect plants from damage by disease by inhibiting the growth of F. *oxysporum* until the 8th week when the percentage of disease incidence has increased. It showed that endophytic fungi significantly promote the shallots' growth and control plant disease, as well as the same result study by Yu et al. (2021).

Table 1. Percentage incidence and severity of Fusarium wilt disease in Dayak onion at 5, 6, 7, and 8 weeks after planting

Treatments	Disease incidence (%) (Weeks After Planting)				Disease severity (%) (Weeks After Planting)			
	5	6	7	8	5	6	7	8
No treatment	0 a	25 c	50 d	75 d	0 a	25 c	50 c	62.5 d
Fs	50 c	100 d	100 e	100 e	35 c	60 c	65 e	75 e
MEnI + MEnK	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a
FsMEnI	25 b	50 c	50 d	50 b	25 b	50 c	37.5 b	50 b
FsMEnK	0 a	25 b	50 b	50 bc	0 a	25 b	37.5 b	50 c
FsMEnI+FsMEnK	0 a	50 c	50 c	50 c	0 a	50 c	50 d	50 b

Notes: The same letters indicate no significant difference between treatments (n=4, Duncan Sig 0.05 in the same colomn). **Control**=no treatment**;** **Fs**: pathogen F.oxysporum; **MEnI+MEnK**: endophytic fungi *F. solani* (EnI) and *Neoscytalidium* sp. (EnK); **FsMEnI**: endophytic fungi extract F.solani (EnI) + pathogen *F. oxysporum*; **FsMEnK**: endophytic fungi *Neoscytalidium sp*. (EnK)+ pathogen *F. oxysporum* ; **FsMEnI+FsMEnK**: endophytic fungi *Fusarium solani* (EnI) and *Neoscytalidium sp*. (EnK)+pathogen *F. oxysporum*

The high incidence and severity of disease in the treatment of *F. oxysporum* (Fs) and control are due to the activity of *F. oxysporum,* which spreads faster and is more adaptable so that it can attack shallot bulbs easily compared to the application of endophytic fungus extracts, according to Ibrahim & Abadi (2023), which states that the high pathogen attack in the treatment of *F. oxysporum* is due to the active pathogen, which causes a faster spread in attacking plants. Chang et al. (2021) said that the disease incidence was reduced significantly by soil inoculation with fungal endophytes, and it can be seen in Table 1. The shallot, whose seed has been treated by endophyte and soil inoculated with the extract, has lower symptoms than the control plant. The antioxidant activity may burst from the endophyte, significantly inhibiting the infection and colonization of the Fusarium wilt pathogen (Lv et al., 2024).

The presence of *an F. oxysporum* pathogen attack is indicated by the symptoms of leaf decay from the base to the tip of the leaf, leaves growing in circles or moler, yellowing of leaves, lodging, necrosis, and death (Figure 5), which began to appear at 5 weeks after planting. Herlina et al. (2020) stated that the symptoms of Fusarium wilt in shallots begin with the pale green color of the leaves; the leaves grow twisted and yellow; the plants look like they will collapse, wither, and brown roots; and there are whitish fungal colonies on the layered bulbs. This is different from the treatment of plants applied with *F. oxysporum* and endophytic fungal extracts together (FsMEnI; FsMEnK; and FsMEnI+FsMEnK). There are symptoms of Fusarium wilt characterized by the wilting of several leaves from the base to the top, wilted leaves, and collapse but did not lead to plant death until 8 weeks after planting (Figure 5). The endophytes had delayed the wilt symptoms in shallots, as reported by Trizelia et al. (2023), that endophytic fungi from cotton roots have not only delayed but also reduced the incidence of wilt disease. It's because the endophyte has a role in promoting chlorophyll content, leaf number, and plant height besides the pathogen attack (Wang et al., 2024). Plant that treatment with fungal endophytes provides the protection from pathogen attack. Endophytic fungi have signaled to induce systemic resistance (Koshy et al., 2025) by increasing enzyme defense activity like chitinase peroxidase and β-1,3-glucanase in a way to hydrolyze the pathogen cell wall (Shobha et al., 2019).

Figure 5. Comparison of yield of shallot bulbs applied with endophytic fungus extracts EnI (*Fusarium solani*) and EnK (*Neoscytalidium* sp.) and pathogen *F. Oxysporum.* The treatments were **(a)** no treatment; **(b)** pathogen *F.oxysporum* (FS); **(c)** MEnI+MEnK: endophytic fungi extract *F. solani* (EnI) and *Neoscytalidium* sp. (EnK); **(d)** FsMEnI: endophytic fungi extract *F.solani* (EnI)+ pathogen *F. oxysporum*; **(e)** FsMEnK : endophytic fungi extract *Neoscytalidium* sp. (EnK)+ pathogen *F. oxysporum*; **(f)** FsMEnI+FsMEnK: endophytic fungi extract *Fusarium solani* (EnI) and *Neoscytalidium* sp. (EnK)+pathogen *F. oxysporum*

The use of endophytic fungus extracts of Dayak onion flowers has the potential as a biological material for controlling Fusarium wilt in shallots that protects plants from pathogen attack by increasing plant resistance. The ability of endophytic fungus extracts to control the pathogen *F. oxysporum* that causes moler disease is carried out by producing secondary metabolites so as to increase plant resistance and inhibit pathogen growth. Pachorkar & Pawar (2025) said that endophytic fungi can release secondary metabolites in the form of bioactive compounds that can inhibit the development of pathogen cells in host plants. Then, the volatile organic compound that is produced by endophytic fungi can suppress the incidence of disease (Syam et al., 2022). Endophytic fungi performed well to inhibit leaf blight symptoms' incidence and severity by suppressing necrotic symptoms (Membalik et al., 2021). As we can see in the Table 1, shallots with endophyte treatments have 50% lower disease and severity symptoms than the shallots with no treatment (Fs) (75-100%).

The endophytic fungi of Dayak onion flowers, EnI and EnK, have antagonistic activity to inhibit the growth of the pathogen *F.oxysporum.* Rizali et al. (2021) reported that the application of endophytic fungi from Dayak onion flowers has a percent inhibition on the pathogens *F. oxysporum* in vitro, *F. solani* EnI 71.09%, and *Neoscytalidium* sp. EnK 38.54%, respectively. So the use of endophytic fungus extracts of dayak onion flowers EnI and EnK can have a good impact on controlling *F. oxysporum,* which causes Fusarium wilt disease. Endophyte fungi have hydrolytic enzymes known to degrade fungal cell walls (Thimmappa et al., 2024) and Fusarium itself is reported to have ligninolytic enzymes involved in degrading high-molecular-weight compounds and secreting manganese peroxidase (Zhang et al., 2020).

CONCLUSION

Endophytic fungus extracts from Dayak onion flowers, EnI (*Fusarium solani*) and EnK (*Neoscytalidium* sp.), were able to inhibit fusarium wilt disease by reducing the percentage of disease incidence and severity by 50%. The application of endophytic fungal extracts from Dayak onion flowers EnI (*Fusarium solani*) and EnK (*Neoscytalidium* sp.) increased the number of leaves, plant height, and fresh weight, indicating that they can support shallot growth while suppressing disease development. These results suggest that Dayak onion flower endophytic fungal extracts have potential as environmentally friendly biological control agents against Fusarium wilt in shallots.

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AUTHORS' CONTRIBUTIONS

NS and RRA designed and conceived of the experiments. The experiment was conducted by J, AR, RAS, and TDN. NS contributed to the preparation of samples and interpretation of the results. The manuscript was primarily composed by TDN. All authors provided critical feedback and contributed to the development of the research, analysis, and manuscript.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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